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Dredging Research
Technical Notes

Hydrologic Surveys Applicable to Dredging Operations

Purpose

This technical note documents a survey of existing geophysical equipment and techniques for dredging use. Information presented herein provides planners and operators guidance in selecting appropriate equipment and geophysical techniques applicable to specific project objectives.

Background

For years, the Corps relied mainly on boring studies to identify the physical properties of materials to be dredged. Some geophysical techniques were used, but to a limited degree. Boring studies are costly, often provide limited information, and omit important details pertaining to cost overruns of some studies. Additionally, new dredging operations cannot be conducted until an accurate assessment of site archeology had been made. Department of the Army Dredging Guidance Letter (March 13, 1989) mandates certain remote sensing requirements, such as magnetometer surveys.

Geophysical surveys, when properly executed, can greatly enhance the interpretation of bottom and subbottom site conditions, particularly when integrated into well planned boring and laboratory testing programs. Such continuous surveys provide an efficient, cost-effective means of acquiring virtually continuous coverage as opposed to potentially dangerous extrapolations between distantly spaced boreholes. All too often, dredging contractors are awarded valid claims based upon limited or incorrect information gleaned from such interpretations. Relatively new geophysical technology based upon seismic digital data acquisition and interpretation procedures is now available to provide more reliable, cost-effective information necessary for a more complete site assessment.

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Introduction

The primary objective of this study was to locate and evaluate existing state-of-the-art high-resolution geophysical equipment and techniques to determine the physical properties of bottom and subbottom materials for dredging. A secondary objective was to determine the most efficient equipment and techniques for the rapid identification of pertinent items, such as density and material type, to enable Corps assessment of bottom conditions on a predredging and postdredging basis, the prime motivator being complete site assessment with maximum cost savings.

An equipment survey evaluated the effectiveness of existing geophysical methods for determining the physical properties of the dredged material. The survey included a literature review and personal contact discussions with equipment manufacturers, other developers, petroleum exploration engineers, university scientists, and various Federal agencies with similar interests. This approach was structured to offer the dredging community a better understanding of what a geophysical survey can do and how it will help eliminate certain problems that arise when dredging projects are undertaken.

This technical note briefly presents geophysical techniques thought to be directly applicable to dredging projects. Primary emphasis is placed on acoustic subbottom profiling because of its potential rate of return per dollar spent. A brief discussion of the acoustic impedance concept (data acquisition and visualization) is rendered. Other techniques, such as ground probing radar (GPR) and resistivity, will be addressed to a lesser degree because of their lower state of development for application to dredging operations. An overview of navigation and the importance of adequate planning also are presented.

Geophysical Systems and Methods

Acoustic Profiling Systems

Profiling systems have been used for several years to aid engineers, geologists, archaeologists, and oceanographers in determining the nature of stratigraphy below the bottom of a water body.

High-resolution engineering seismic surveys are confined to relatively shallow depths. By far the greatest percentage of this engineering work is actually done in the upper 45 to 60 ft of subbottom material. Typical applications

include, but are not limited to, reconnaissance geological surveys, geotechnical characterization, mineral exploration, foundation studies for locks and dams, harbor development, cable/pipeline crossing surveys, cultural resources (archeological) surveys, and dredging.

Acoustic subbottom profilers, side scan sonars, and magnetometers are state-of-the-art equipment specifically designed to undertake bottom and subbottom investigations. They are widely used in all phases of underwater construction projects and search operations.

High-resolution "pinger" and "boomer" acoustic profiling systems are used to collect subbottom data which is printed on a graphic recorder as a continuous two-dimensional profile. The graphic recorder contains control functions which permit optimum display of reflected signals in "shades of gray." It is considered the key component in waterborne seismic reflection systems. The amount of penetration will depend on the combination of frequency and power selected. It also will depend on the material type which composes the bottom and subbottom. In conjunction with private contractors, the US Army Engineer Waterways Experiment Station (WES) has developed and is presently testing and improving a high-resolution geophysical system to determine soil characteristics by acoustic impedance. A prototype system was assembled as part of the Dredging Research Program (DRP) in 1989-90. That system has been tested on dredging projects at several different sites on the east and west coasts of the United States. The results of these tests have correlated well with boring analysis ("ground truth") in the areas surveyed.

Dredging Application. Seismic profiles obtained with high-resolution systems in conjunction with boring data can be used to construct continuous cross sections of areas without interpolation between boreholes. Data can then be processed into three-dimensional color isometrics of the dredge cut and can be used to calculate the amount of material to be removed. Additionally, material density is calculated and color-coded, and the predicted material type tabulated. Figure 1 is an example of a three-dimensional density-coded project presentation (all original density presentations are color-coded for easy visualization). Note: The figure presented here is in black and white.

Data Acquisition Procedures. Most acoustic surveys use a predetermined grid pattern with lines spaced at variable distances, depending on objectives of the survey. Small survey boats (30 to 65 ft long) are adequate for performing a complete multisystem survey. Over-the-side and surface-towed source/receiver arrays should be towed at speeds not exceeding 4 to 6 knots. If this rate of speed is exceeded, the quality of acoustic data may deteriorate. In some cases, however, hull-mounted transducers may operate satisfactorily at speeds up to 20 knots or more. Additional factors affecting the towing speed of acoustic source/hydrophone arrays are firing rates of the source, horizontal scale of the record desired, and survey boat design. Data acquisition must be interfaced with the navigation system so that accurate information between position and data is recorded at all times.

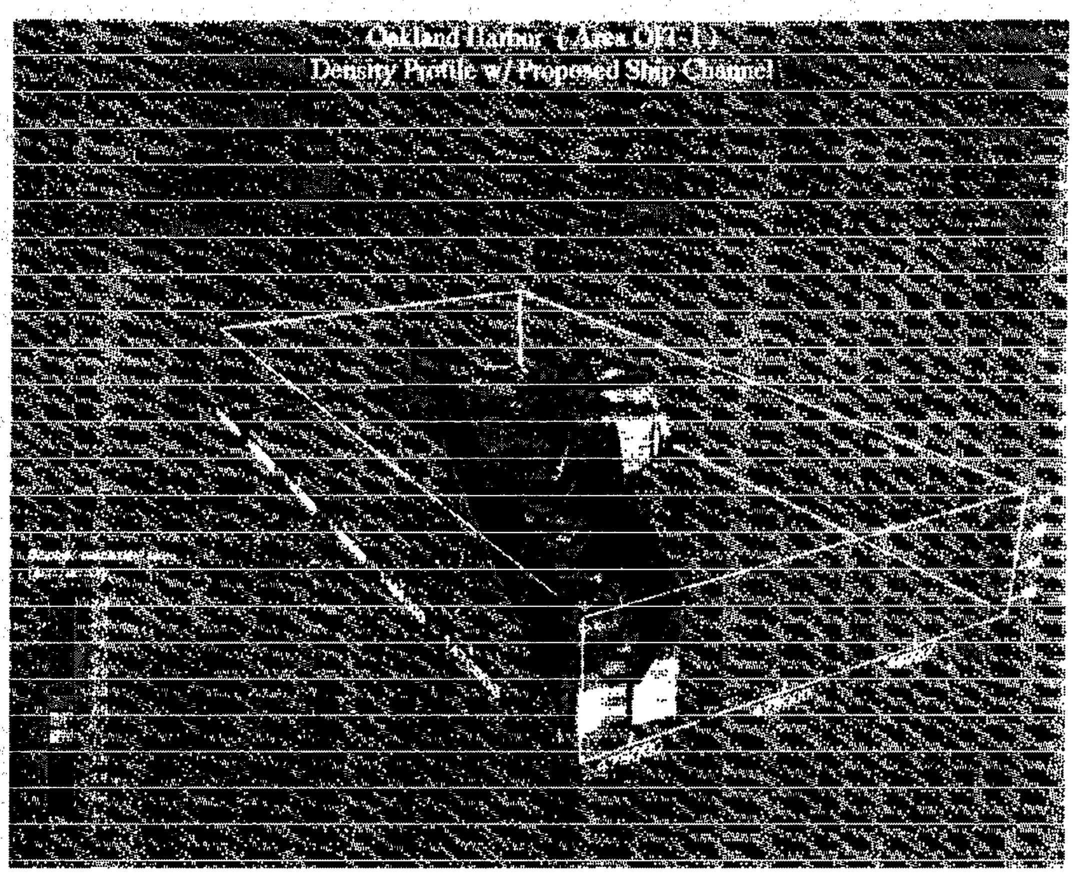

Figure 1. Computer-projected three-dimensional density profile

Data Interpretation. Because the seismic source transducer is a three-dimensional sound source, care must be given to the interpretation of seismic profiling records obtained with conventional two-dimensional graphic recorders. This is particularly true in those instances where the bottom or subbottom traversed has considerable deformation or anomalies. In general, five different types of spurious signals exist that may cause confusion in data interpretation: direct arrival, reflection multiple, water surface reflections, side echoes, and point-source reflections. Any of these types of signals can be misinterpreted as real data.

Advantages and Limitations. Primary advantages associated with acoustic subbottom profiling are continuous documentation of reflecting strata, rapid coverage, and relatively low cost. The elimination of two or three borings can, in most instances, pay for a complete survey. In some cases, even the lack of reflections, such as from discontinuous strata, can yield valuable information.

The quality of records obtained in seismic reflection studies depends greatly on the presence of subsurface horizons which will reflect acoustic energy. Differences in soil types, density, water content, and degree of solidification greatly influence the reflecting properties of the subbottom strata. Other factors affect the success of a seismic reflection survey. These may be

conveniently grouped into four classes: external (noise, weather conditions, and boat traffic), vessel (size, mechanical condition, and operator), instrument (age, alignment, and selection), and operator/technician (ability, experience, and knowledge of survey operations). Seismic profiles are essentially useless unless the precise location of the survey line is known.

Seismic records show layer thickness as a function of time; thus, the true thickness can only be determined if the speed of sound through the material is known. Absolutely accurate sound wave velocity data are seldom available; therefore, layer thicknesses must be considered as close approximations.

Subtle changes in the reflected signal do not always represent a change in the soil type, but may be only a change in a physical characteristic of the soil, such as grain sphericity, porosity, or density. Therefore, care must be exercised in evaluating the strength (darkness) of the record signal. Acoustic impedance processing techniques appear to offer advantages in data processing by using parameters other than the strength of the signal. Impedance calculations are based upon absorption as a function of frequency.

As water depth increases, the area of seafloor receiving seismic energy also increases. Because of the beam angle of the transducers, records in deep water will tend to show average conditions over an area rather than a specific profile directly below the ship. Future studies involving beam-forming approaches to data acquisition will appreciably narrow these effective beam widths so that a predetermined "window" size can be selected.

The operator/technician is an extremely important element of the seismic survey. Seismic equipment manufacturers advertise that anyone can operate their equipment, and this is basically true. However, on a multisystems survey, numerous operational and technical problems may arise which can result in poor quality data or downtime. A qualified equipment specialist will be able to eliminate many of these problems by recognizing poor quality data when it occurs. Such an operator can be expected to optimize control settings for the best signal quality.

Radar

Under certain circumstances, seismic acoustic methods are severely hampered by multiple reflections which may occur in shallow water. Under such circumstances, radar could be a viable high-resolution alternative to differentiation of subbottom materials to depths of tens of feet in fresh water. Studies conducted by the US Geological Survey in cooperation with the Federal Highway Administration have shown potential usefulness of this technique. In the course of this study, it was found that Ground Probing Radar (GPR) proved highly effective for detecting subbottom layering. Because dredging operations often require sharp definition to top of rock, the application of radar could provide meaningful information (with accuracies approaching a few inches) as a supplement to acoustic subbottom profiling in those instances where freshwater operations are taking place.

The most obvious advantage of a GPR survey is the speed with which it can be conducted. High vertical and horizontal resolution capabilities are other attributes. GPR can survey through asphalt and concrete provided there are not large amounts of rebar material present. By selecting the proper antennas (which are available from 80 MHz through 1 GHz) the depth of the investigation and resolution capabilities can be varied. GPR can survey through freshwater and, under certain circumstances, detect organics floating on groundwater or even heavier-than-water concentrations of contaminants.

Since waterborne applications of GPR are sparsely documented, a wide range of advantages and limitations is yet to be developed. One severe limitation is known to exist. When conductivity of the medium (whether liquid or solid) is high, depth of the investigation may be virtually nonexistent or limited to inches rather than feet. Examples of materials with high conductivity include salt water, conductive organics, and fat clays. One must bear in mind, however, that absence of data (signal return) also can be quite meaningful.

Resistivity

The electrical resistivity of seafloor materials depends mainly on their porosity, pore water salinity, and mineralogy (mainly grain size and clay content). Therefore, measurement of the electrical resistivity of seafloor materials can provide information about geotechnical properties of interest for dredging investigations. Along with porosity and grain size, geotechnical properties that can be determined from resistivity data include sediment density, degree of consolidation, depth and thickness of subbottom layers, and depth to bedrock.

Some of the limitations associated with geotechnically oriented acoustic techniques do not apply to resistivity measurements. First, acoustic measurements generally require minimum water depths of about 5 to 10 ft to avoid problems caused by surface reflection effects. Resistivity measurements can be made in any water depth and, in fact, generally become more accurate with decreasing water depth. Second, the presence of interstitial gas in seafloor sediments often attenuates acoustic signals to the point where no usable acoustic data can be obtained. Experience with resistivity measurements in a variety of marine environments indicates that gas content levels that completely attenuate acoustic signals have no measurable effect on resistivity data.

Electrical resistivity methods have a number of disadvantages compared with acoustic techniques. Because resistivity is directly related to water salinity, salinity effects must be considered when interpreting resistivity values in terms of geotechnical parameters. The necessity of towing a relatively long cable behind the survey vessel is quite an operational disadvantage compared with acoustic reflection techniques. Because resolution of subseafloor resistivity properties increases as the elevation of the cable above the seafloor decreases, it is desirable to tow the cable along the seafloor rather

than within the water column or at the surface. Although cables as long as several thousand feet have been towed along the seafloor with minimal problems, the possibility of snagging and cable damage exists.

Since the electrical resistivity measurement provides a center-weighted average of properties of material beneath the cable, the inherent vertical and lateral resolution of resistivity data is not as good at that provided by high-frequency acoustic measurements. Finally, although computer algorithms for interpretation of waterborne resistivity data are available, such algorithms are relatively slow and do not presently permit data interpretation at the desired rate of a few seconds per station for real-time display. Future development will minimize this restriction.

Acoustic and resistivity methods for waterborne geotechnical investigations are complementary. Therefore, combined use of the strengths of the two techniques would provide considerably more confidence in interpreted geotechnical parameters than the use of either method alone. Although prototype towed-array resistivity systems have been used successfully, the state of development of waterborne resistivity hardware and interpretation techniques is not as advanced as for acoustic systems. Development of fast interpretation algorithms and construction of transmitter-receiver and computer data acquisition systems for routine survey use are possible using available hardware and software technology, but at present these capabilities are yet to be exploited.

Navigation Systems

The best data obtainable are useless unless the exact location of that data is known. Several types of navigation systems are used by the Corps of Engineers today — all having the ability to locate X,Y coordinates within a few feet. In most instances, however, the navigation systems are separate from the geophysical data collection systems. The chances for error are significant. By combining or integrating the navigation and geophysical data acquisition systems, the chance for error in minimized. Future navigation systems will undoubtedly incorporate the Global Positioning System (GPS), which will be available through the DRP for Corps of Engineers applications in the near future. At present, horizontal two-dimensional surveying accuracy is on the order of a few feet, but the complete GPS (with its satellites, receiving hardware, and processing software) will offer three-dimensional accuracy to within a few inches.

Planning

Preparation for a predredging survey should be given careful consideration. The spacing and the length of grid lines should be sufficient to cover the entire area to be dredged with a minimum of interpolation. The selection will vary, depending on known geologic formations, the criteria, and the number of hazards present. Survey lines should be preplotted with capabilities of

generating new lines while the survey is in progress to ensure that anomalies discovered during the survey can be thoroughly investigated.

The surveying equipment should include, but not be limited to, pinger, boomer, side-scan sonar, magnetometer, Fathometer, data storage, and associated equipment. Such an integrated system will monitor conditions above the bottom, on the bottom, and below the bottom.

Boring sites should be selected after analysis of the subbottom profile records. This will ensure that all the different types of material present will be sampled and also minimize the number of borings. Boring information should be analyzed, logged, and compared to the subbottom records. The exact depth of the subbottom strata can be corrected on the subbottom profile records. Continuous two-dimensional cross sections can then be constructed from the subbottom profile records without interpolation. The volume of different types of materials in the survey area can be calculated using the constructed cross section with a high degree of accuracy. Three-dimensional displays of bottom and subbottom material descriptors can be constructed as a worthwhile aid to project engineers.

Summary

In the course of this survey, it was discovered that a wide variety of instruments can be configured to accomplish many different objectives. An effective assembly would incorporate a number of subsystems into an integrated data management and navigation master system. Thus, several techniques could be applied simultaneously while performing one grid pattern search. Not only would such an approach be cost effective, but complementary data would yield a more accurate assessment of site conditions.

Six types of equipment were surveyed for applicability to the Corps of Engineers dredging program. Each was found to be applicable to varying degrees. Acoustic methods, however, were found to excel in terms of proven capability and versatility. Recent developments in computer software technology have greatly enhanced data acquisition and interpretation procedures. Acoustic methods also readily lend themselves to interpretations based upon impedance and reflectivity of bottom and subbottom materials. This approach will be of direct benefit to dredging studies because density and material descriptors are indirect outputs — both are related to the degree of effort required for dredging. Additionally, if acoustic surveys were employed prior to dredging, optimum channel center lines could be selected to minimize rock removal, thereby minimizing project costs.

Methods using the principles of electromagnetics and electrical currents may well complement the acoustic techniques when further developed. Magnetometers will provide information related to dredging hazards and presence of cultural resources.